ADA

EFFECTS OF VARIOUS CORROSION INHIBITORS/LUBRICITY (CI/LI) ON FUEL FILTRATION PERFORMANCE

INTERIM REPORT
TFLRF No. 394

by

Gary B. Bessee

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. DAAE-07-99-C-L053 (WD43)

March 2008

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14. ABSTRACT

Research had been performed by an industry cooperative program determining the effects of various military aviation fuel additives on filtration performance. One of the conclusions of this research was DCI 4A corrosion inhibitor has detrimental effects on water separation performance of fuel-water separators.

The objective of this project was to verify previous research's conclusions that DCI 4A corrosion inhibitor caused detrimental water removal effects. API/IP 1581 5th Edition C-model filter-water separators were evaluated using DCI 4A corrosion inhibitor at 15, 10, 5, and 0 mg/L with duplicates at 5 and 0 mg/L.

All data supports the conclusion that the lower the DCI 4A corrosion inhibitor concentration, the less impact this additive has on water separation performance. Results with only static dissipater (Stadis 450) and fuel system icing inhibitor (Di-egme) generate on specification data similar to Jet A that contains no additives.

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EXECUTIVE SUMMARY

<u>Problems:</u> Aviation fuel additives are known to have detrimental effects on water separation performance of fuel/water separators. Previous research has suggested DCI 4A corrosion inhibitor is the major contributor in JP-8.

<u>Objective:</u> The objective of this project was to verify previous research conclusions that DCI 4A corrosion inhibitor caused detrimental water removal effects. API/IP 1581 5th Edition C-model filter-water separators were evaluated using DCI 4A corrosion inhibitor at various concentrations.

<u>Importance of Project:</u> This research could lead to improved fuel for the field, reduce maintenance, and improve fuel/water separation characteristics by reducing the concentration of DCI 4A or changing to other types of approved corrosion inhibitors.

<u>Technical Approach:</u> The research was a continuation of research previously funded by the U.S. Air Force, U.S. Army, and commercial oil companies. The test protocol used the test protocols described in API/IP 1581 5th Edition but changed the order of the challenges.

<u>Accomplishments:</u> The research confirmed the conclusions from the previous research that DCI 4A has detrimental impact on water removal performance, and illustrated that without any DCI 4A the filtration performance met API/IP 1581 5th Edition specifications.

<u>Military Impact:</u> These results can improve the fuel quality for the soldiers in the field by either reducing the additive concentration or changing corrosion inhibitor to a different chemistry that is on the approved QPL.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period May 2007 through March 2008 under Contract No. DAAE-07-99-C-L053. The U.S. Army Tank-Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Luis Villahermosa (AMSRD-TAR-D/MS110) served as the TARDEC contracting officer's technical representative. Mr. Kenneth Walther (AMSRD-TAR-D/210, MS110), Fuel and Water Support Team, TARDEC, served as the project technical monitor.

The author would like to acknowledge the assistance of Messrs. Raymond Lemes and Max Reinhard, Jr., SwRI, for conducting the filtering testing and Ms. Rebecca Emmot for her administrative report.

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1.0 INTRODUCTION AND BACKGROUND

Recent work has reported a severe effect of added CI/LI additives on water separation in jet fuels.[1] These additives are standard packages in military fuels but are being found increasingly in civilian fuels, especially as these latter are under pressure to have sulphur levels reduced. Currently, the supplier is required to notify the customer that such additives were injected into civilian fuels. However, at the 2006 AFC meeting in Farnborough, UK, a proposal to drop this notification was made. Furthermore, jet fuels delivered via multi-product pipelines have been known to become cross-contaminated by similar additives developed for automotive diesel fuels, and while work is in progress to examine the broader issues raised by this, past work indicates a negative impact on jet fuel performance. Protocols exist to help pipeline operators assess the acceptability of individual additives introduced for one fuel type in terms of the impact on other fuels they may handle.

Originally, a cooperative R&D program was planned to evaluate CI/LI additive's effect on filtration efficiency using an API/EI 1581 5th Edition C-model filter-water separator and the test protocol developed previously for the +100 additive program with TFLRF being one of the participants. However, the commercial industry was not interested in pursuing this research. Therefore, the scope of work was reduced to fit the available TFLRF funding.

2.0 OBJECTIVE AND APPROACH

The objective of this project was to verify previous research conclusions that DCI 4A corrosion inhibitor caused detrimental water removal effects. API/IP 1581 5th Edition C model filter-water separators were evaluated using DCI 4A corrosion inhibitor at 15, 10, 5, and 0 mg/L with duplicates at 5 and 0 mg/L. API/IP 1581 5th Edition test protocol was utilized for all six evaluations.

3.0 TEST DATA

The test protocol utilized for this research was the same as used in the evaluation of various additives, including +100. The baseline data (Jet A) from this research will be used as a comparison with these results to assess the effects of DCI 4A corrosion inhibitor. All test fuels contained the recommended concentrations of Stadis 450 and fuel system icing inhibitor (FSII). The variable for all of these evaluations was the concentration of DCI 4A.

The test protocol is described below:

- Pre-conditioning with clean, dry fuel—15 minutes
- 100-ppm water challenge—60 minutes
- 5,000-ppm water challenge—30 minutes
- 3% water challenge—10 minutes
- 90% ISO 12013-1 A-1 test dust/10% red iron oxide—10-psid increase from initial differential pressure at the start of this phase or 2 hours.

The cumulative test time for the test protocol will be used for data analysis below. The order of testing was as follows:

- 0-ppm DCI 4A
- 15-ppm DCI 4A
- 10-ppm DCI 4A
- 5-ppm DCI 4A
- 0-ppm DCI 4A
- 5-ppm DCI 4A

The test order was randomized to ensure no bias in the data with the 0-ppm DCI 4A duplicates performed at the extremes of the test matrix for confidence in the data. Summaries for each evaluation detailing the maximum water or solids value for each section are provided below with the full data sheets provided in Appendix A. In addition to the normal gravimetric and water analysis by Aqua-glo, on-line particle counting and turbidity measurements were taken to provide additional information on the filtration performance with these additives.

The particle counting analysis can determine an object is present but cannot differentiate between water and solid particles. The turbidity analysis is performed at two angles with the 25° signal representing water, and the 90° signal representing solid contamination. The turbidity is the haziness of the test fuel and is caused by the scattering of light, due to either water or solid contamination. The units for turbidity are Nephelometric Turbidity Units (NTU). Clean fuel will have very low values, whereas contaminated fuel will have higher values.

3.1 Test #1—0-ppm DCI 4A

Table 1 provides the summary for the first evaluation using 0-ppm DCI 4A, 1 mg/L Stadis 450, and 0.15% FSII.

Table 1. Maximum Values for Test #1—0-ppm DCI 4A

Test Section	Maximum Effluent Water Content, ppm	Maximum Solids Content, mg/L
Pre-conditioning	<1	n/a
100-ppm water challenge	3	n/a
5,000-ppm water challenge	5	n/a
3% water challenge	4	n/a
Solids challenge	n/a	0.1

The particle count and turbidity data for Test #1 are provided in Figures 1 and 2, respectively. As mentioned above in the test protocol description, the time is the total test time of the evaluation.

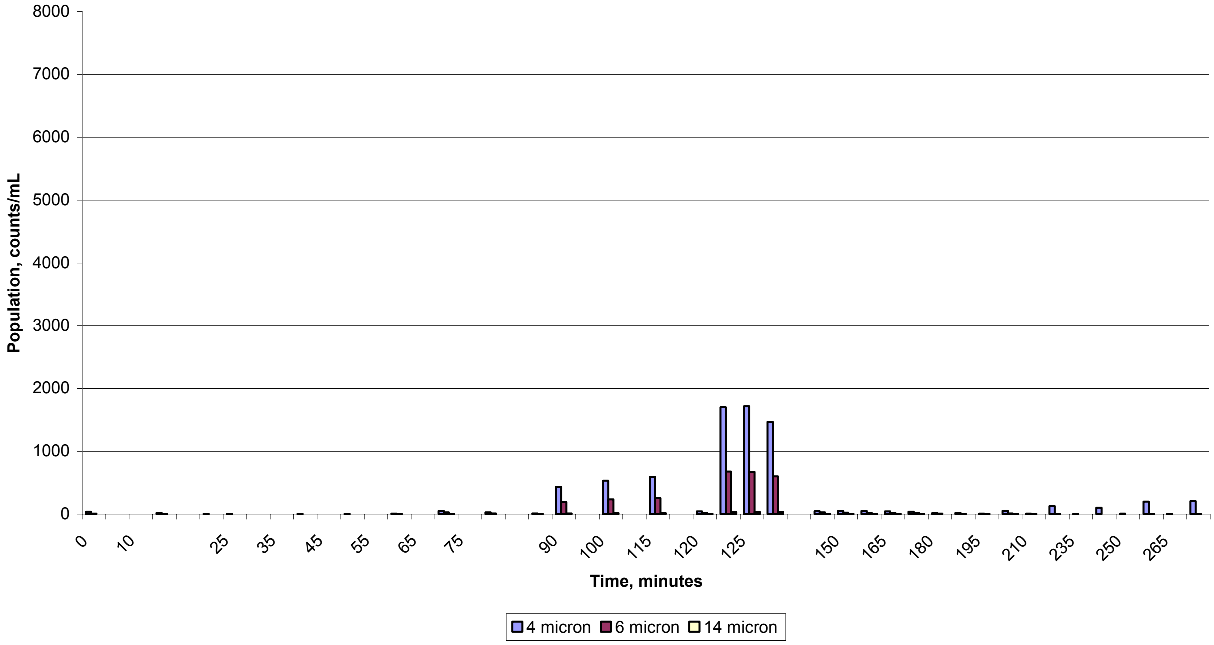

Figure 1. Particle Counting for Test #1—0-ppm DCI 4A

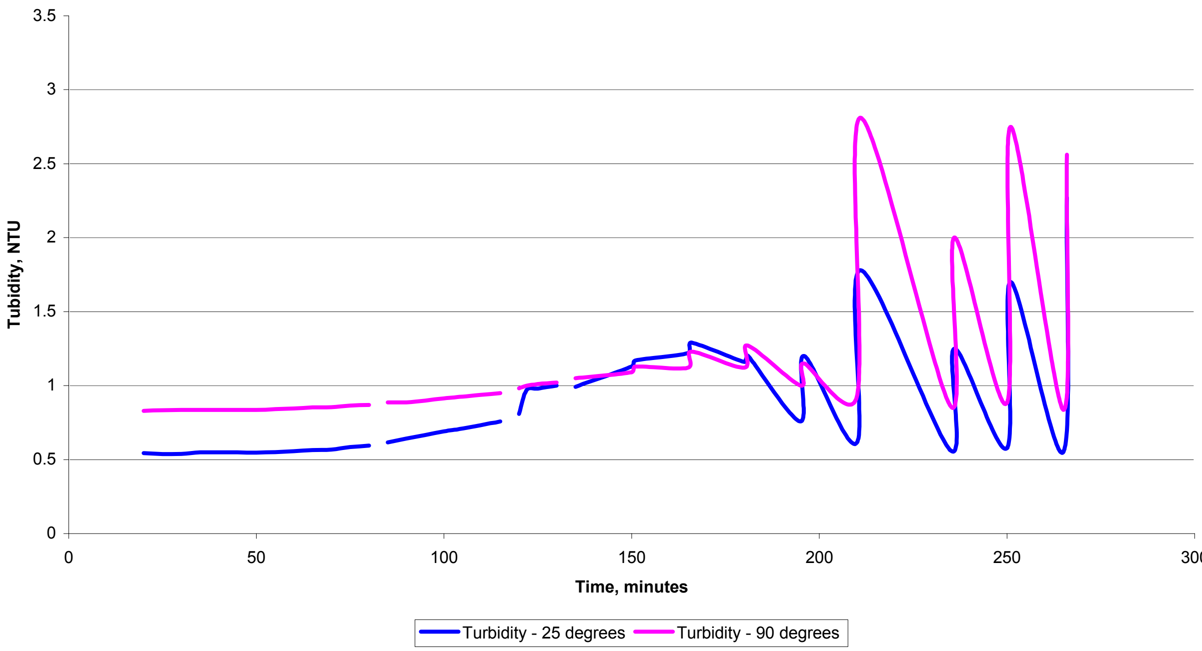

Figure 2. Turbidity Measurements for Test #1—0-ppm DCI 4A

3.2 Test #2—15-ppm DCI 4A

Table 2 provides the summary for the first evaluation using 15-ppm DCI 4A, 1 mg/L Stadis 450, and 0.15% FSII.

Table 2. Maximum Values for Test #2—15-ppm DCI 4A

Test Section	Maximum Effluent Water Content, ppm	Maximum Solids Content, mg/L
Pre-conditioning	1	n/a
100-ppm water challenge	2	n/a
5,000-ppm water challenge	2	n/a
3% water challenge	>30	n/a
Solids challenge	n/a	0.0

The particle count and turbidity data for Test #2 are provided in Figures 3 and 4, respectively.

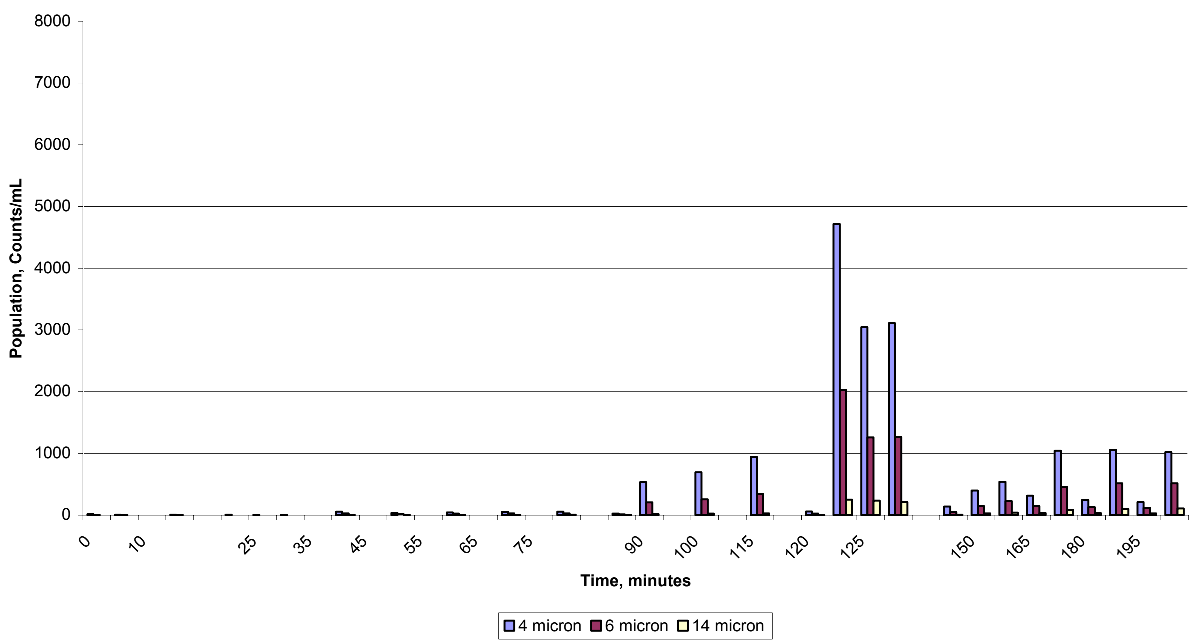

Figure 3. Particle Counting for Test #2—15-ppm DCI 4A

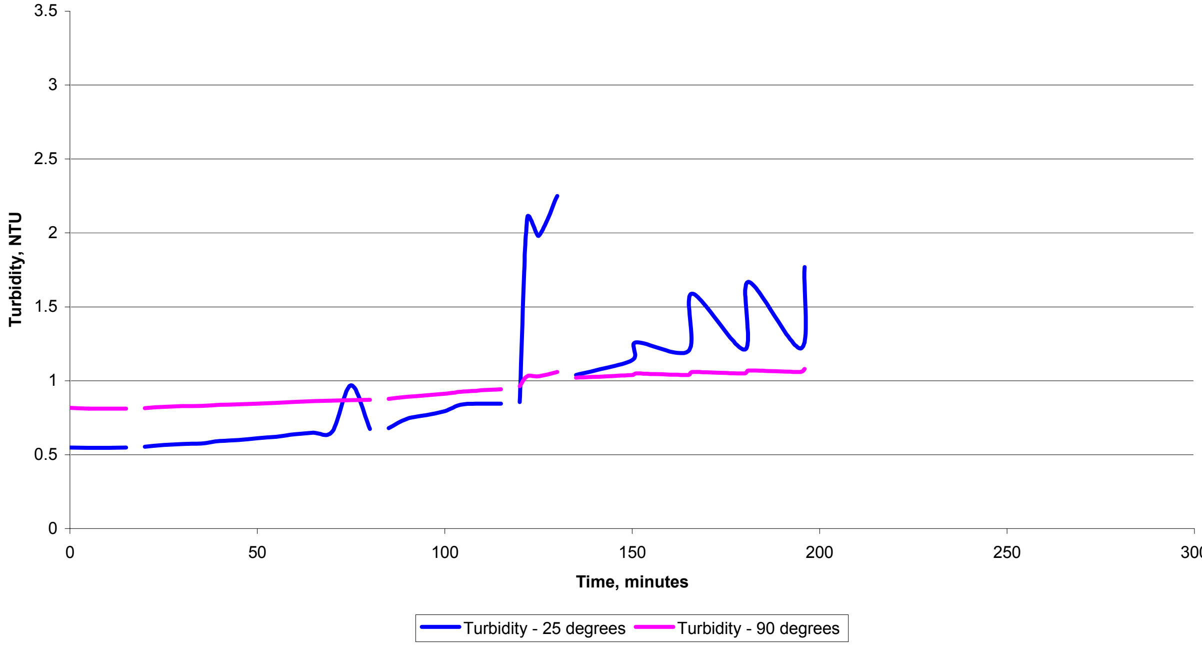

Figure 4. Turbidity Measurements for Test #2—15-ppm DCI 4A

3.3 Test #3—10-ppm DCI 4A

Table 3 provides the summary for the first evaluation using 10-ppm DCI 4A, 1 mg/L Stadis 450, and 0.15% FSII.

Table 3. Maximum Values for Test #3—10-ppm DCI 4A

Test Section	Maximum Effluent Water Content, ppm	Maximum Solids Content, mg/L
Pre-conditioning	1	n/a
100-ppm water challenge	6	n/a
5,000-ppm water challenge	5	n/a
3% water challenge	45	n/a
Solids challenge	n/a	0.15

The particle count and turbidity data for Test #3 are provided in Figures 5 and 6, respectively.

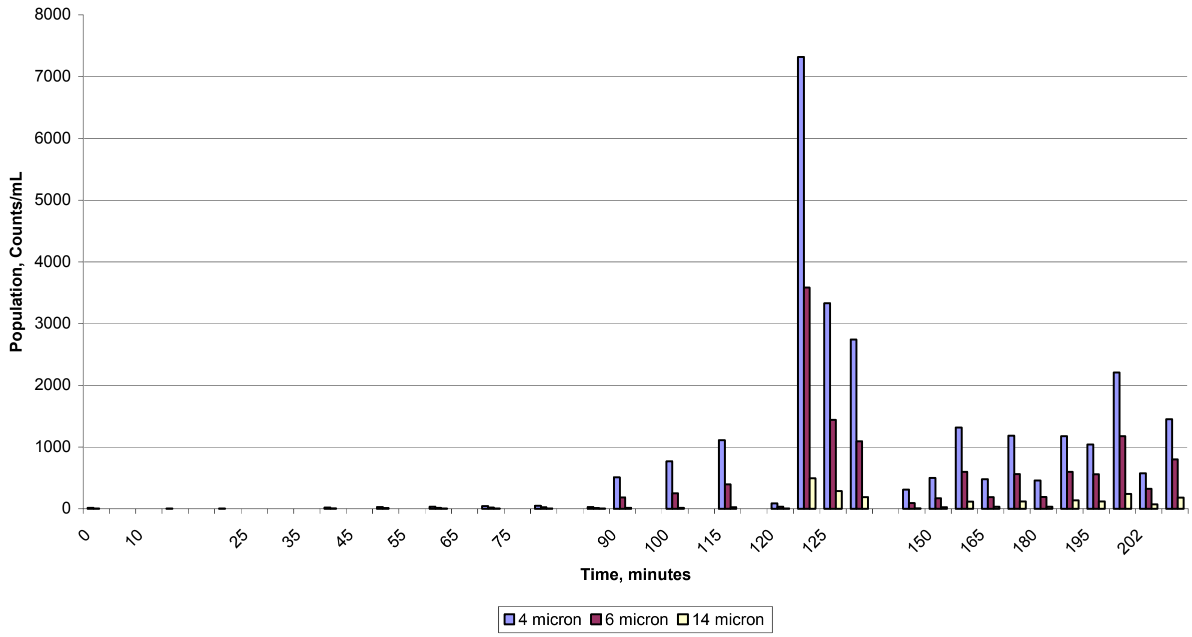

Figure 5. Particle Counting for Test #3—10-ppm DCI 4A

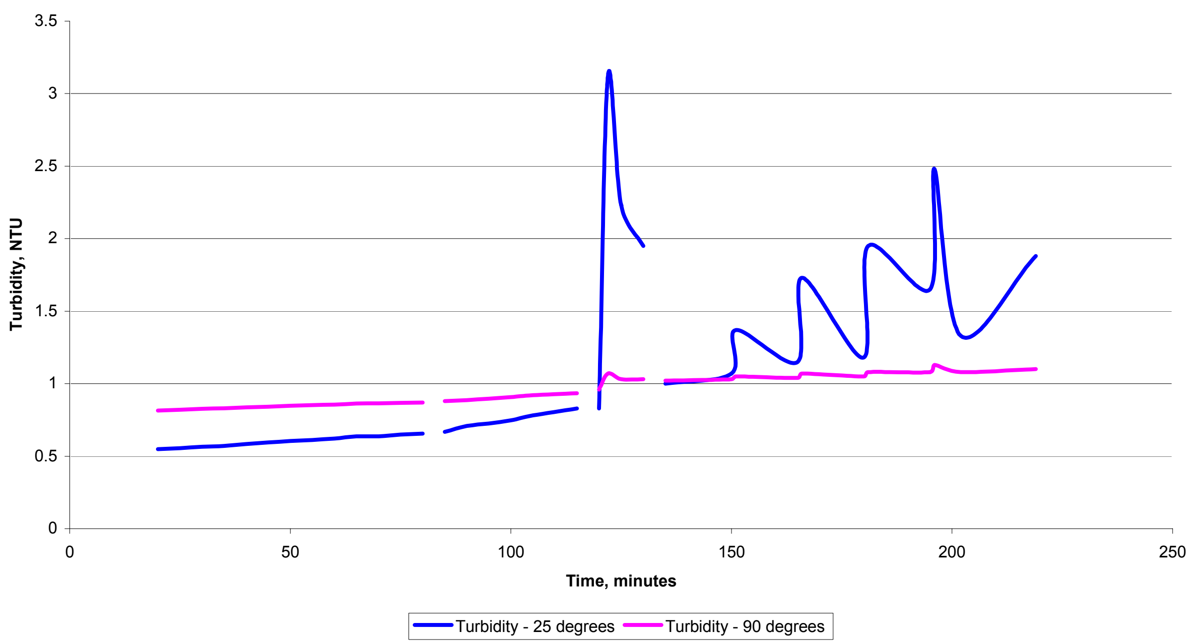

Figure 6. Turbidity Measurements for Test #3—10-ppm DCI 4A

3.4 Test #4—5-ppm DCI 4A

Table 4 provides the summary for the first evaluation using 5-ppm DCI 4A, 1 mg/L Stadis 450, and 0.15% FSII.

Table 4. Maximum Values for Test #4—5-ppm DCI 4A

Test Section	Maximum Effluent Water Content, ppm	Maximum Solids Content, mg/L
Pre-conditioning	1.5	n/a
100-ppm water challenge	3	n/a
5,000-ppm water challenge	9	n/a
3% water challenge	17.5	n/a
Solids challenge	n/a	0.15

The particle count and turbidity data for Test #4 are provided in Figures 7 and 8, respectively.

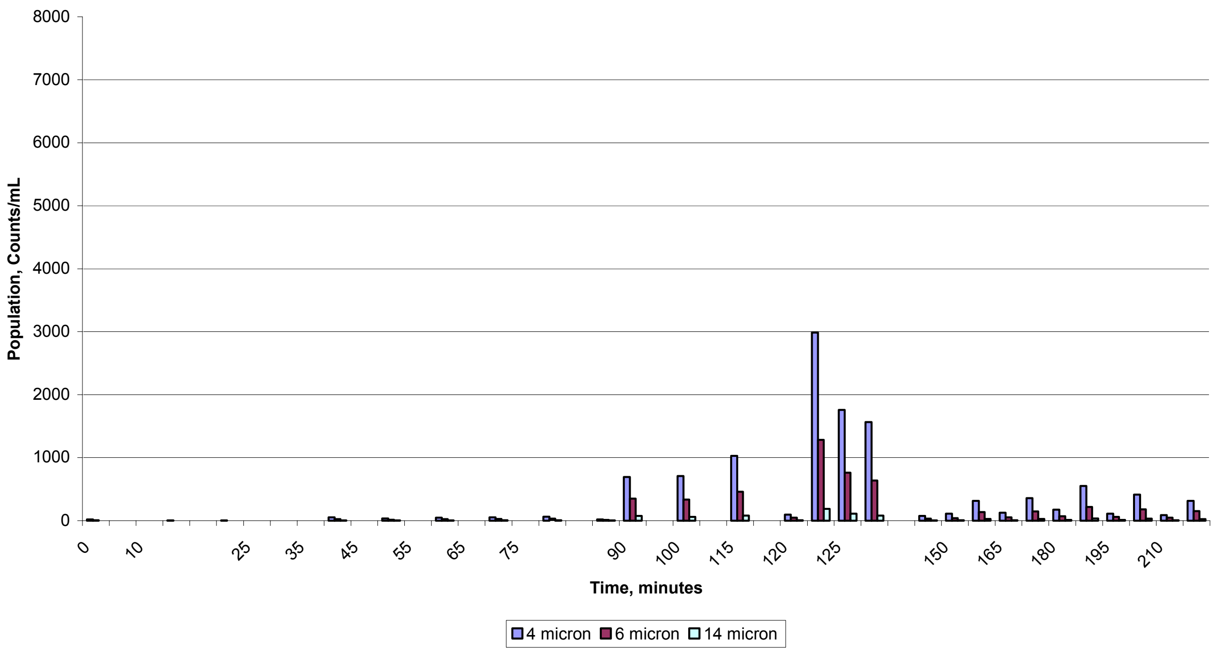

Figure 7. Particle Counting for Test #4—5-ppm DCI 4A

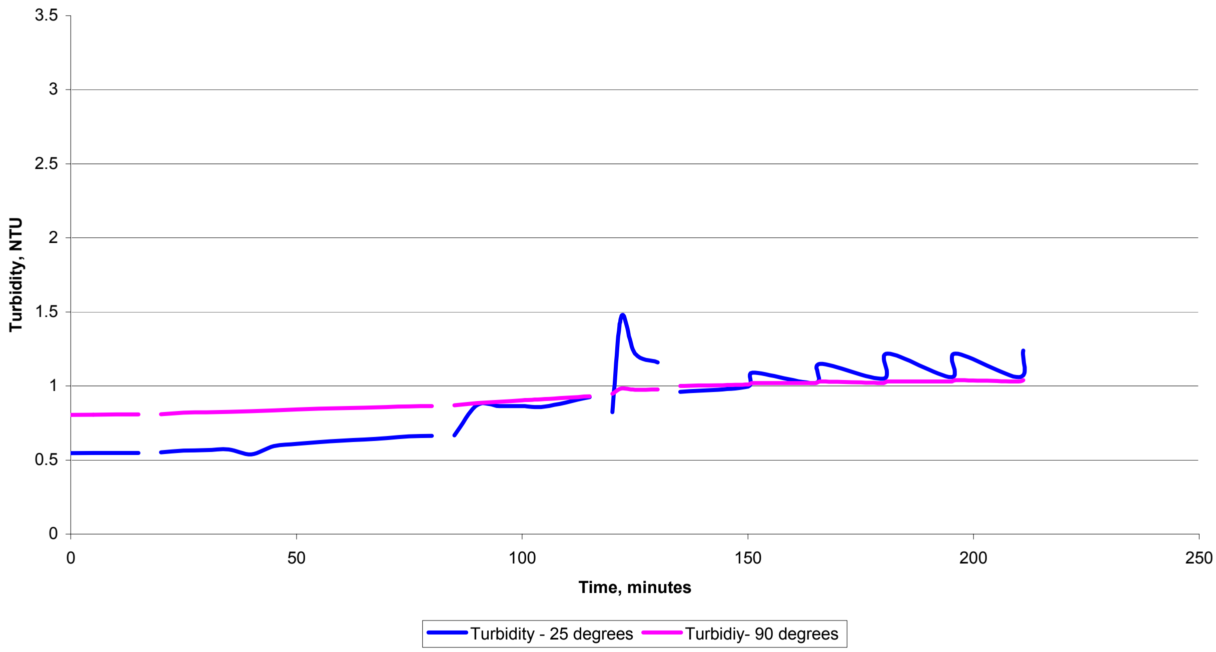

Figure 8. Turbidity Measurements for Test #4—5-ppm DCI 4A

3.5 Test #5—0-ppm DCI 4A

Table 5 provides the summary for the second evaluation using 0-ppm DCI 4A, 1 mg/L Stadis 450, and 0.15% FSII.

Table 5. Maximum Values for Test #5—0-ppm DCI 4A

Test Section	Maximum Effluent Water Content, ppm	Maximum Solids Content, mg/L
Pre-conditioning	1	n/a
100-ppm water challenge	3	n/a
5,000-ppm water challenge	2	n/a
3% water challenge	4.5	n/a
Solids challenge	n/a	0.15

The particle count and turbidity data for Test #5 are provided in Figures 9 and 10, respectively.

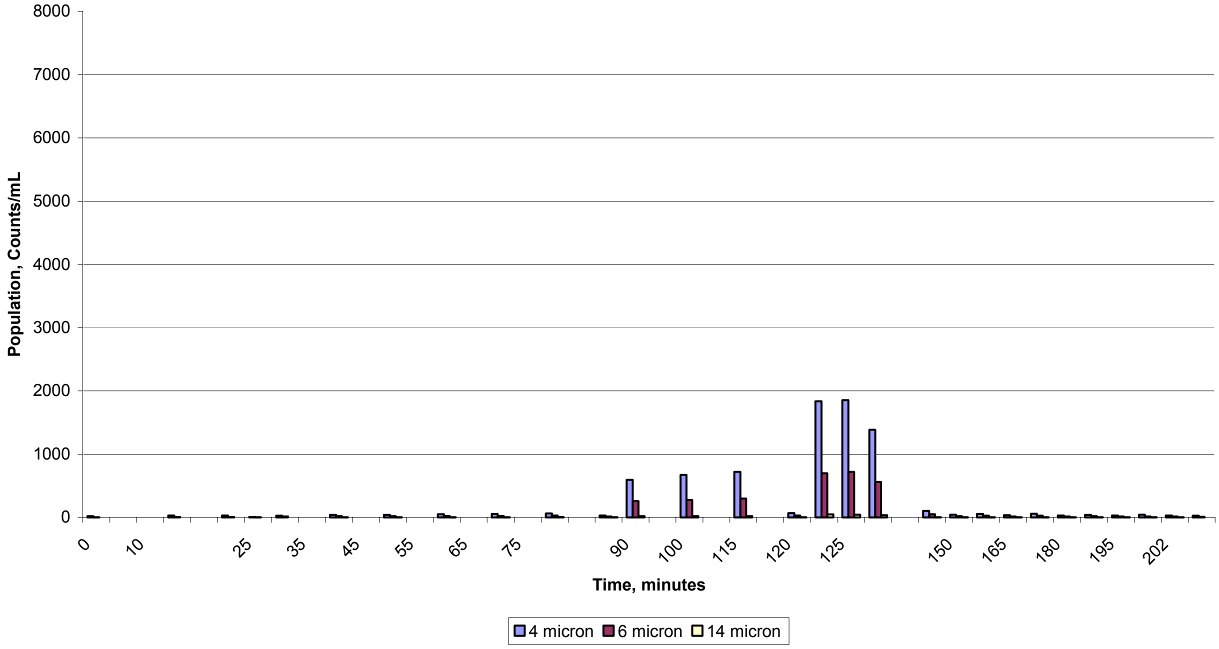

Figure 9. Particle Counting for Test #5—0-ppm DCI 4A

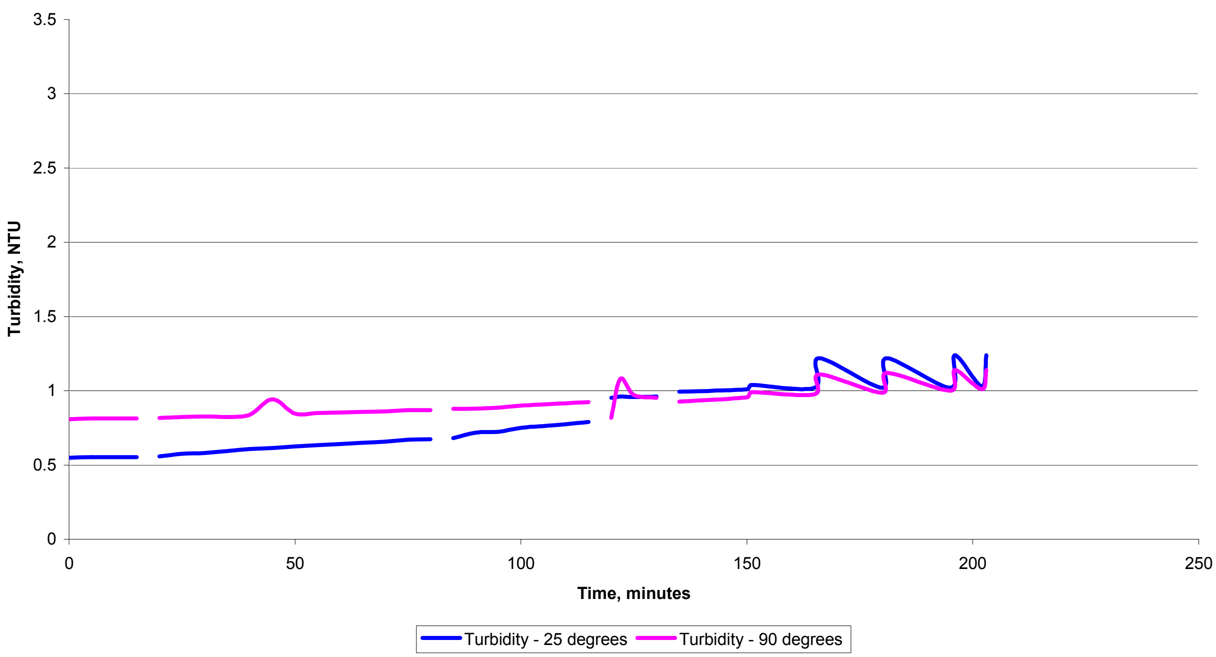

Figure 10. Turbidity Measurements for Test #5—0-ppm DCI 4A

3.6 Test #6—5-ppm DCI 4A

Table 6 provides the summary for the second evaluation using 5-ppm DCI 4A, 1 mg/L Stadis 450, and 0.15% FSII.

Table 6. Maximum Values for Test #6—5-ppm DCI 4A

Test Section	Maximum Effluent Water Content, ppm	Maximum Solids Content, mg/L
Pre-conditioning	1.5	n/a
100-ppm water challenge	2	n/a
5,000-ppm water challenge	2	n/a
3% water challenge	2	n/a
Solids challenge	n/a	0.0

The particle count and turbidity data for Test #6 are provided in Figures 11 and 12, respectively.

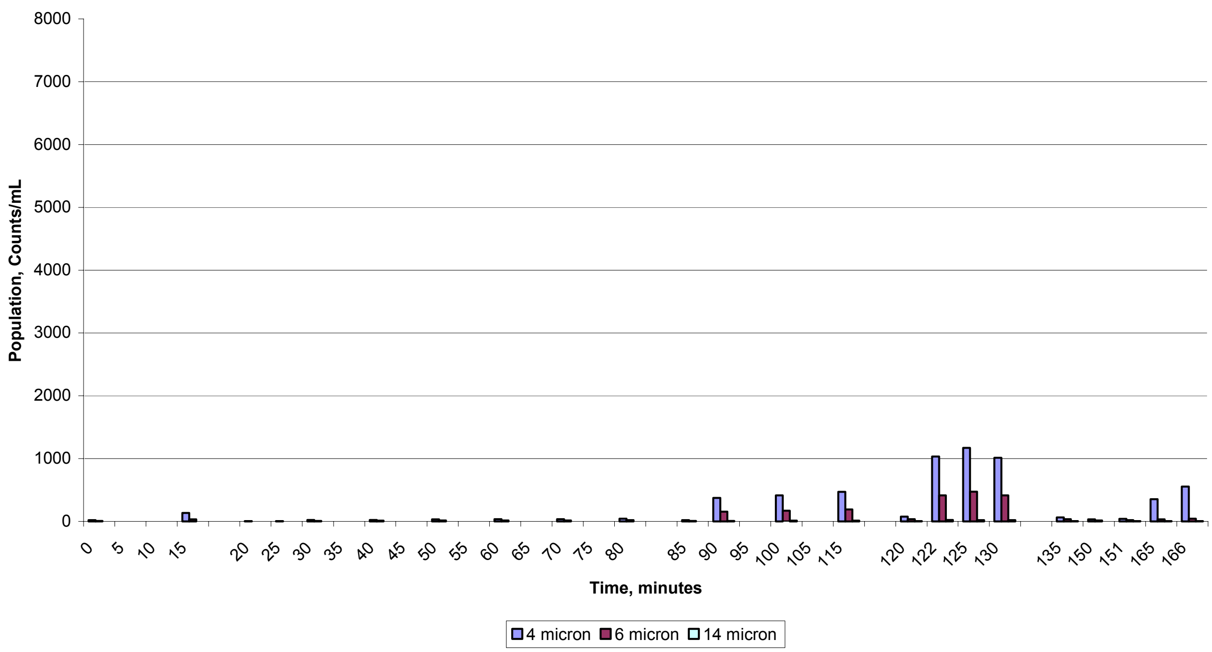

Figure 11. Particle Counting for Test #6—0-ppm DCI 4A

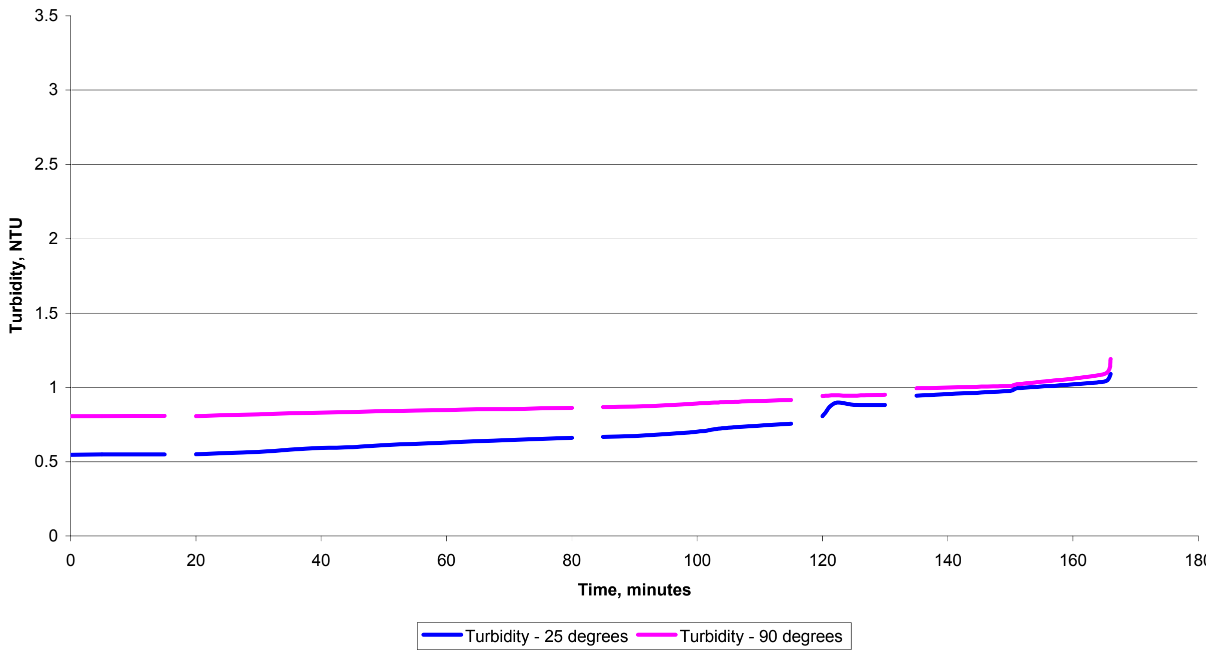

Figure 12. Turbidity Measurements for Test #6—5-ppm DCI 4A

3.7 Differential Pressure

The differential pressure for each element for the entire test protocol is shown in Figure 13. The dotted lines are the repeats at 0 and 5-ppm DCI 4A. Test elements #1 and #6 appear to be slightly different. This could have been a difference in the construction of the test filter. Test #1 has a longer life that might indicate it is slightly more open than the other test elements. Test element #6 is just the opposite with the short filter life, as indicated by the steep slope during the solids loading, may be a result of a tighter media construction. The rest of the pressure measurements are very similar.

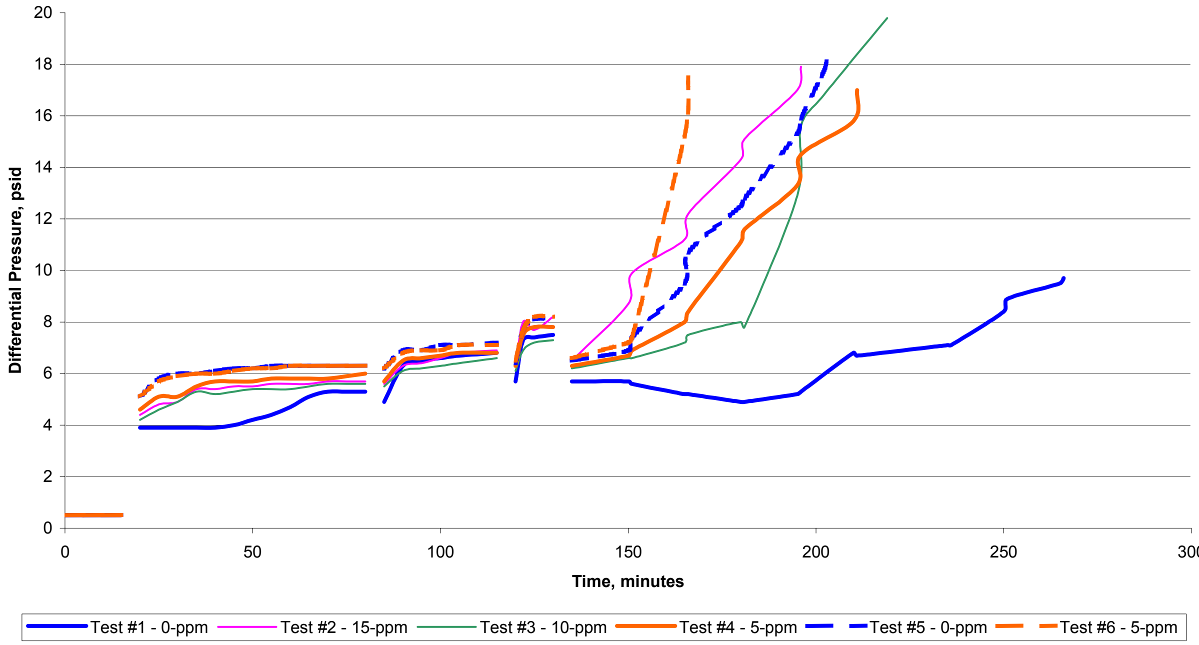

Figure 13. Differential Pressure of Each Test Element

3.8 Discussion of Results

Phase II of the Aviation Cooperative R&D Program included evaluations at 0, 11, and 22-ppm of DCI 4A with and without the others additives used to formulate JP-8. The water content for the 3% water challenge for all of these evaluations were typically much greater the 15-ppm limit, as measured by Aqua-glo.

As shown in Table 7, the effluent water content for the 3% water challenge increases as a function of DCI 4A concentration. The effluent water content at 0-ppm of DCI 4A is that of Jet A.

Table 7. Maximum Effluent Water Content for 3% Water Challenge

DCI 4A Concentration, ppm	Maximum Effluent Water Content, ppm
0-ppm, Test #1	4
0-ppm, Test #5	4.5
5-ppm, Test #4	17.5
5-ppm, Test #6	2
10-ppm, Test #3	45
15-ppm, Test #2	>30

Both the particle count and turbidity data supports the Aqua-glo results. The 10 and 15-ppm of DCI 4A particle count data has maximum values approaching 5,000 and 7,000 counts/mL, whereas the 0-ppm DCI 4A is less than 2,000 count/mL for the 3% water challenge. The turbidity has similar results with the turbidity being the greatest (>2 NTU) at 25° for the 3% water challenge, whereas the 0-ppm results are approximately 1 NTU.

4.0 CONCLUSIONS

The purpose of this research was to determine if initial conclusions that DCI 4A corrosion inhibitor was detrimental to water removal performance, as found in the Aviation Filtration Cooperative R&D program. Due to funding constraints, only a small test matrix was performed at various concentrations to make this determination. In addition to the Aqua-glo analysis, particle count and turbidity data were used to make the conclusions. The only variable in the test matrix was the DCI 4A concentration. All data supports the conclusion that the lower the DCI 4A corrosion inhibitor concentration, the less impact this additive has on water separation performance. Results with only static dissipater (Stadis 450) and fuel system icing inhibitor (Di-egme) generate data similar to Jet A which contains no additives.

5.0 REFERENCE

1. Southwest Research Institute (SwRI) Aviation Fuel Filtration Cooperative R&D Program, SwRI Project 08-10844, Gary Bessee, Janet Buckingham, and Vic Hughes, February 2006.

APPENDIX

WD 43 - Test #3 - Jet A with Stadis 450 and FSII, no DCI4A

			Conductivity		Aqua-glo	Gravimetric	IFT	Temp	Turbidity			Particle Counts				
Time	Flow rate, gpm	DP	Upstream	Downstream	ppm	mg/L	mN/m	F	25	90	4	6	14	21	25	30
Pre-conditioning																
0	3	0.5	434	112	<1		43.44	84	0.561	0.858	40	7	0	0	0	0
5	3.3	0.5	430	189												
10	3.1	0.5	429	250												
15	3	0.5	427	360	<1			84	0.543	0.832	19.1	3.1	0.1	0	0	0
100 ppm water challenge																
0	33.3	3.9	430	387	1			88	0.543	0.828	3.9	0.4	0	0	0	0
5	33.1	3.9	420	389	1			87	0.537	0.834	2.3	0.5	0.1	0.1	0.1	0
10	33	3.9	417	390	1			87	0.538	0.835	1.1	0.2	0	0	0	0
15	33.1	3.9						87	0.548	0.835						
20	33	3.9	419	390	1.5			87	0.548	0.835	2.2	0.6	0.1	0	0	0
25	33.2	4						87	0.548	0.836						
30	32.9	4.2	413	400	2			87	0.547	0.836	3.1	0.7	0.1	0	0	0
35	33.1	4.4						87	0.55	0.84						
40	33.2	4.7	410	402	2			87	0.557	0.846	6.6	2.1	0.1	0.1	0.1	0
45	32.9	5.1						87	0.564	0.853						
50	33.1	5.3	417	411	3			87	0.568	0.855	52.9	26.4	4	0.9	0.5	0.3
55	33.1	5.3						87	0.584	0.865						
60	32.9	5.3	413	409	2.5		43.05	87	0.594	0.87	26.5	13.2	1.8	0.3	0.1	0.1
0.5% water challenge																
0	32.9	4.9	421	415	2.5			87	0.616	0.886	12.1	5.6	1.2	0.1	0	0
5	33.2	6.3	426	454	2.5			87	0.642	0.886	436.1	196.4	13.9	3.6	2.1	1.1
10	33.1	6.5						88	0.666	0.898						
15	32.9	6.6	427	465	3			88	0.691	0.913	534.1	234.9	17	4.8	2.1	1.2
20	33.1	6.7						88	0.71	0.925						
30	32.8	6.8	434	466	5		43.75	88	0.757	0.95	592.5	256.9	17.1	4.1	1.7	0.5
3% water challenge																
0	33.3	5.7	439	439	3.5			88	0.808	0.981	45.4	21	3.1	0.7	0.2	0.1
2	33.1	7.3	444	549	3			89	0.97	0.998	1703.2	677.2	35.3	9.6	4.8	1.9
5	33.1	7.4	444	566	3			89	0.98	1.01	1717.4	675.5	34.9	9.5	4.1	1.4
10	33.3	7.5	457	564	4			89	1	1.02	1471.3	601.9	35	10.1	4.5	2.2
Solids																
0	32.9	5.7	450	468		0.05		89	0.992	1.05	49.1	26.8	3	0.2	0.2	0.2
15	33	5.7	453	472		0.05		90	1.13	1.09	51.1	25	2.8	0.6	0.3	0
16	33.1	5.6	455	470		0		90	1.17	1.13	50.3	21	2.2	0.4	0.2	0.1
30	33.1	5.2	451	469		0		90	1.22	1.12	43.9	21.4	2.4	0.5	0.1	0.1
31	33.4	5.2	452	463		0.05	44.18	90	1.29	1.23	40.4	19.3	2.4	0.2	0.1	0.1
45	33.2	4.9	447	453		0		90	1.16	1.12	15.6	8.1	1.9	0.5	0.2	0.1
46	33.4	4.9	436	442		0.01		90	1.2	1.27	20.6	5.6	0.6	0.2	0	0
60	33.1	5.2	440	397		0.05		90	0.757	1	8.5	3.6	0.5	0	0	0
61	33.8	5.3	438	395		0		90	1.2	1.15	56.5	10.1	2.5	0.4	0.1	0.1
75	33	6.8	442	391		0.05		90	0.615	0.927	8.9	2.8	0.3	0	0	0
76	33.3	6.7	436	385		0.1		90	1.78	2.81	129.4	3.6	0.4	0.1	0	0
90	33.2	7.1	441	377		0.1		89	0.561	0.86	3.4	1.1	0.1	0	0	0
91	33.6	7.1	138	375		0		89	1.25	2	102.3	1.6	0.1	0	0	0
105	33.2	8.4	432	370		0.05		88	0.578	0.883	7.3	1	0.1	0	0	0
106	33.3	8.9	450	371		0		88	1.7	2.75	198.2	2.3	0.1	0	0	0
120	32.9	9.5	432	367		0		88	0.55	0.837	3	0.3	0.1	0.1	0.1	0.1
121	32.8	9.7	439	370		0.01		88	2.27	2.56	208	2.4	0	0	0	0

WD 43 - Test #2 - Jet A with Stadis 450 and FSII, 15 ppm DCI4A

			Conductivity		Aqua-glo	Gravimetric	IFT	Temp	Turbidity			Particle Counts				
Time	Flow rate, gpm	DP	Upstream	Downstream	ppm	mg/L	mN/m	F	25	90	4	6	14	21	25	30
Pre-conditioning																
0	3.1	0.5	524	258	1		40.7	78	0.548	0.817	14.9	4.4	0.1	0	0	0
5	3.3	0.5	533	293					0.546	0.811	9.9	2.9	0.1	0	0	0
10	3.2	0.5	519	304					0.547	0.811						
15	3.1	0.5	510	315	1			78	0.548	0.812	8.6	2.1	0	0	0	0
100 ppm water challenge																
0	32.9	4.4	531	410	1			75	0.553	0.815	7.9	1.9	0	0	0	0
5	33.1	4.8	5.4	437	1			75	0.566	0.824	2.1	0.6	0.1	0.1	0.1	0.1
10	32.9	4.9	490	450	1.5			75	0.573	0.829	2.1	0.9	0.1	0	0	0
15	32.9	5.4						75	0.576	0.83						
20	32.9	5.4	551	482	1.5			75	0.593	0.837	55.8	26.6	4.7	1.3	0.9	0.6
25	33.1	5.5						75	0.6	0.84						
30	32.9	5.5	555	500	2			75	0.612	0.846	36.1	17.9	3.4	1	0.5	0.3
35	33.1	5.6						75	0.622	0.85			.			
40	32.9	5.6	556	512	2			75	0.639	0.857	42.9	23.4	4.3	1.6	1.4	0.9
45	33.1	5.6						75	0.649	0.862						
50	32.9	5.7	562	531	2			75	0.657	0.866	50.6	27.1	5.6	1.1	0.8	0.4
55	33.1	5.7						75	0.97	0.869						
60	33	5.7	561	527	2		38.5	75	0.674	0.872	55.3	28.3	6	1.6	1	0.6
0.5% water challenge																
0	33	5.6	555	415	2			75	0.68	0.878	25.4	11.6	2.1	0.4	0.3	0.3
5	32.9	6.3	563	454	2			76	0.743	0.892	534	206.4	17.6	5.6	2.9	1.8
10	32.9	6.4						76	0.767	0.901						
15	32.8	6.6	556	465	2			76	0.794	0.912	694.2	255.9	23.2	8.1	4.4	2.3
20	33.1	6.8						76	0.841	0.928						
30	33.1	6.9	554	466	2		41.4	76	0.846	0.943	945.7	344.4	28.9	11.1	6.1	3.5
3% water challenge																
0	32.9	6.3	552	500	1.5			76	0.856	0.963	60.3	24.3	3.9	0.9	0.5	0.4
2	33.4	8	555	482	25			76	2.1	1.03	4714.6	2030.5	249.9	114.6	82.9	54.8
5	33.3	7.7	549	501	20			77	1.98	1.03	3044.3	1258.9	233.8	132.8	99.1	70
10	33.4	8.2	546	498	>30			77	2.25	1.06	3110	1262.6	212.2	117.2	88.1	65.5
Solids																
0	32.9	6.5	557	520		0		77	1.04	1.02	139.4	47.6	8.1	3.4	2.7	1.9
15	33.1	8.7	557	544		0		77	1.14	1.04	399.9	141.8	26.4	9.4	7.9	5.4
16	33.1	9.9				0		77	1.26	1.05	543.1	226.9	40.3	13.4	10	7.6
30	32.8	11.2	552	561		0		77	1.2	1.04	316.3	148.8	33.3	12.9	10.4	7.5
31	33.1	12.2				0		77	1.59	1.06	1043.8	458.3	83.1	28.7	22	14.8
45	32.9	14.3	564	564		0		78	1.21	1.05	245.8	127.2	30.3	11.5	8.7	6.2
46	33.2	15.1				0		78	1.67	1.07	1054.4	512.6	102.3	35.9	25.7	17.7
60	33	17	559	565		0		78	1.22	1.06	209.5	119.1	28.1	11.2	9.1	6.6
61	33.1	17.9				0		78	1.77	1.08	1018.6	515.6	108.7	36.1	26.6	19.1

WD 43 - Test #3 - Jet A with Stadis 450 and FSII, 10 ppm DCI4A

			Conductivity		Aqua-glo	Gravimetric	IFT	Temp	Turbidity			Particle Counts				
Time	Flow rate, gpm	DP	Upstream	Downstream	ppm	mg/L	mN/m	F	25	90	4	6	14	21	25	30
Pre-conditioning																
0	3.1	0.5	644	172	1		37.26	78	0.546	0.815	14.1	4.1	0.1	0	0	0
5	3.1	0.5	642	243												
10	3	0.5	648	260												
15	3.1	0.5	659	270	1			78	0.546	0.815	5.4	1.5	0.1	0	0	0
100 ppm water challenge																
0	33.1	4.2	659	406	1			77	0.549	0.815	2.5	0.6	0.1	0	0	0
5	33.1	4.6	642	520	1			77	0.556	0.82	1.9	0.6	0	0	0	0
10	33.1	4.9	636	520	1.5			77	0.566	0.827	1	0.4	0	0	0	0
15	33.1	5.3						77	0.571	0.83						
20	33.1	5.2	669	564	2			77	0.585	0.837	18.8	8.2	0.6	0.2	0.1	0.1
25	33.2	5.3						77	0.594	0.841						
30	33.1	5.4	678	597	3			77	0.604	0.848	26.8	11.7	1.7	0.4	0.1	0.1
35	33.1	5.4						77	0.612	0.852						
40	33.1	5.4	678	618	6			78	0.622	0.856	30.2	14.9	2.6	0.6	0.4	0.2
45	32.9	5.5						78	0.636	0.862						
50	33.1	5.6	674	624	2.5			78	0.637	0.864	42.4	20.9	3.6	1	0.7	0.2
55	33.1	5.6						78	0.648	0.868						
60	33.1	5.6	685	645	3		38.91	78	0.655	0.87	48.2	22.4	4.9	1.1	0.6	0.4
0.5% water challenge																
0	32.9	5.5	679	655	5			78	0.668	0.88	28.8	10.4	2.1	0.5	0.4	0.2
5	32.9	6.1	678	587	3			78	0.709	0.886	511.6	184.1	16.4	7.4	5.2	3.7
10	32.9	6.2						78	0.725	0.896						
15	33.2	6.3	685	609	3			78	0.748	0.906	767.6	250	15.4	5.7	3.4	1.6
20	33.2	6.4						78	0.781	0.92						
30	33.1	6.6	685	613	3.5		41.24	79	0.829	0.934	1114.1	395.3	24.9	10.5	7.4	4.5
3% water challenge																
0	32.9	6.1	689	628	3.5			78	0.829	0.96	87.6	30.7	2.4	0.3	0.2	0.1
2	33.1	6.9	681	628	40			79	3.12	1.07	7318.3	3583.4	493.9	193.4	140.6	95.9
5	32.9	7.2	693	608	45			79	2.23	1.03	3329.2	1438.1	286.7	183.2	142.6	113.4
10	32.9	7.3	696	610	40			79	1.95	1.03	2742.5	1091.1	186.5	117.6	92.6	73.3
Solids																
0	33.1	6.2	682	661		0.05		79	1	1.02	309.6	93.1	8	2.4	1.4	0.7
15	33.1	6.6	690	690		0		79	1.07	1.03	499.4	172.4	24.9	7.5	5.1	3.9
16	33.1	6.6				0		79	1.37	1.05	1316.7	596.6	114.5	32.3	22.3	14.4
30	33.1	7.2	687	705		0		79	1.15	1.04	477.4	187.5	30.3	9.9	7.3	4.5
31	32.9	7.5				0		79	1.73	1.07	1185.4	563.6	118.7	37.9	27.5	19.4
45	33.1	8	696	718		0.05		79	1.18	1.05	456.7	191.6	33.4	10.8	7.2	4.7
46	33.2	7.8				0		79	1.95	1.08	1175.9	597.2	137.2	44.7	30.6	20.4
60	33	12.9	698	706		0		80	1.65	1.08	1041.6	558.4	118.3	40.5	29.5	19.9
61	33.1	15.6				0.15		80	2.48	1.13	2206.5	1176.4	240.4	72.5	50.9	32.2
67	32.9	16.8	697	703		0		80	1.33	1.08	575.9	321.7	73.1	22.5	15.9	10.2
68	33	19.8				0.1	38.73	80	1.88	1.1	1451.6	800.5	177.7	53.9	53.9	35.6

WD 43 - Test #4 - Jet A with Stadis 450 and FSII, 5-ppm DCI4A

			Conductivity		Aqua-glo	Gravimetric	IFT	Temp	Turbidity			Particle Counts				
Time	Flow rate, gpm	DP	Upstream	Downstream	ppm	mg/L	mN/m	F	25	90	4	6	14	21	25	30
Pre-conditioning																
0	3.1	0.5	654	284	1		41.11	80	0.547	0.805	19.6	6.6	0.2	0	0	0
5	3.1	0.5	652	325					0.548	0.807						
10	3.1	0.5	640	333					0.549	0.808						
15	3.1	0.5	637	372	1.5			80	0.549	0.808	3.3	1.1	0.2	0.1	0.1	0.1
100 ppm water challenge																
0	33	4.6	655	431	1.5			77	0.552	0.81	3.7	1.7	0.4	0	0	0
5	33.1	5.1	6.4	500	1.5			77	0.564	0.82	1.9	0.8	0.1	0	0	0
10	33	5.1	651	492	1.5			77	0.567	0.822	1.3	0.6	0.1	0	0	0
15	33	5.5						77	0.573	0.826						
20	33.1	5.7	678	535	2			77	0.538	0.83	50.6	24.7	3.7	1.1	0.5	0.1
25	33.1	5.7						77	0.595	0.835						
30	33.1	5.7	688	572	2			77	0.609	0.842	35.6	16.1	3.2	0.6	0.6	0.4
35	33.1	5.8						77	0.621	0.847						
40	33.1	5.8	685	593	2			77	0.632	0.851	47.3	22.6	4.1	1.5	0.7	0.4
45	33.1	5.8						77	0.639	0.855						
50	33.1	5.8	677	600	2			77	0.648	0.858	52.9	27.6	6.2	1.4	1.1	0.7
55	33.1	5.9						77	0.66	0.863						
60	33.1	6	682	610	3		40.04	77	0.664	0.864	62.4	33.8	7.6	2.6	2.1	1.4
0.5% water challenge																
0	33	5.7	684	620	2			77	0.668	0.87	20	11.1	3.1	1	0.6	0.3
5	33	6.5	690	593	6.5			78	0.871	0.885	694.1	352.6	75.7	39.6	29.2	20.3
10	33.1	6.6						78	0.864	0.893						
15	33.1	6.7	683	596	5			78	0.865	0.903	710.1	333.1	59.9	31.5	23.1	17.2
20	33.1	6.8						78	0.861	0.912						
30	32.9	6.8	681	607	9		41.02	78	0.926	0.931	1027.4	459.9	80.3	42.7	30	21.1
3% water challenge																
0	33.1	6.3	672	612	3			88	0.824	0.948	95.9	49.4	6.2	1.5	1	0.7
2	32.9	7.5	680	605	17.5			89	1.47	0.983	2987.2	1285	188.1	81.9	60.9	41.1
5	33.1	7.8	680	608	12.5			89	1.22	0.974	1758.7	760.6	112.9	63.9	47.4	35.4
10	33.3	7.8	680	606	5			89	1.16	0.977	1567.4	636	79.1	42.9	31.1	23.2
Solids																
0	33	6.3	679	634		0		78	0.962	1	74.3	31.1	3.9	0.9	0.8	0.4
15	33.1	6.7	678	657		0		79	0.997	1.01	110.1	39.6	7.1	2	1.3	0.8
16	33.1	6.9				0		79	1.09	1.02	313.4	135.9	26	7.7	4.9	3.2
30	33.1	8	671	664		0		79	1.02	1.02	128.8	50.4	9.2	3.1	2.4	1.4
31	33.1	8.4				0		79	1.15	1.03	357.1	146.4	28.6	9.1	6.4	4.1
45	33.1	11.1	674	672		0		79	1.05	1.02	173.9	71.8	11.6	4.2	3.1	1.8
46	33.1	11.6				0		79	1.22	1.03	551.6	217.3	33.9	10.4	7.1	4.9
60	33.1	13.3	669	659		0.1		80	1.06	1.03	110.4	57.8	11.4	4.7	3.1	1.8
61	33.1	14.5				0		80	1.22	1.04	413.7	178.5	30	8.1	5.7	3.4
75	33.1	15.8	662	656		0		80	1.06	1.03	89.4	47.6	8.8	3.1	2.1	1.4
76	32.9	17				0.15	41.09	80	1.24	1.04	316.1	150.7	23.2	6.6	3.9	2.4

WD 43 - Test #5 - Jet A with Stadis 450 and FSII, 0-ppm DCI4A

			Conductivity		Aqua-glo	Gravimetric	IFT	Temp	Turbidity			Particle Counts				
Time	Flow rate, gpm	DP	Upstream	Downstream	ppm	mg/L	mN/m	F	25	90	4	6	14	21	25	30
Pre-conditioning																
0	3.1	0.5	580	381	1		42.71	77	0.549	0.808	18	4.5	0.1	0	0	0
5	3.1	0.5	587	451					0.553	0.813						
10	3.1	0.5	591	456					0.554	0.814						
15	3.1	0.5	595	456	1			79	0.554	0.814	32.7	9.4	0.4	0.1	0	0
100 ppm water challenge																
0	33.1	5.1	594	506	1			76	0.558	0.817	30.9	7	0.1	0	0	0
5	32.9	5.8	575	533	1			76	0.575	0.823	8.4	3.6	0.8	0.1	0.1	0.1
10	33.1	6	569	542	1			76	0.58	0.827	29.4	14.1	1.9	0.3	0.2	0.1
15	33.1	6						76	0.594	0.823						
20	33.1	6.1	601	590	1.5			76	0.608	0.839	37.9	18.1	2.5	0.6	0.5	0.4
25	33.2	6.2						76	0.615	0.943						
30	33.1	6.2	605	602	2			76	0.625	0.846	40.6	20.8	3.9	1.1	0.9	0.4
35	33	6.3						77	0.634	0.851						
40	32.9	6.3	608	612	3			77	0.642	0.855	52.5	25	4.1	1.3	0.9	0.5
45	33.1	6.3						77	0.65	0.858						
50	33	6.3	616	625	1.5			77	0.658	0.861	56.3	25.9	4.1	0.8	0.6	0.6
55	32.9	6.3						77	0.671	0.869						
60	32.9	6.3	614	629	2		43.45	77	0.674	0.87	61.9	30.9	6.4	2.4	1.5	0.9
0.5% water challenge																
0	32.9	6.2	615	628	1.5			77	0.681	0.878	32.3	17.4	4.6	1.6	0.9	0.4
5	32.8	6.9	623	641	2			78	0.718	0.879	595.2	260.6	21.2	5.2	3.4	1.3
10	33.1	6.9						78	0.724	0.887						
15	33	7.1	622	644	2			78	0.75	0.9	673.8	273.4	18.6	5.6	3.6	1.7
20	33.1	7.1						78	0.763	0.908						
30	32.9	7.2	628	643	2		39.03	78	0.789	0.923	721.6	297.8	20.2	6.6	3.8	2.2
3% water challenge																
0	33.1	6.4	617	632	3.5			78	0.952	0.818	68.6	33.4	4.5	0.9	0.6	0.3
2	32.3	7.7	625	654	4.5			78	0.962	1.08	1836.9	698.2	47.4	11.9	7.1	3.6
5	32.9	8.1	621	656	2			78	0.957	0.971	1855.4	721.3	43	12.1	6.8	3.4
10	33.1	8.1	628	658	2			78	0.961	0.952	1388.7	563.1	36.7	10.2	5.4	2.6
Solids																
0	33	6.5	628	641		0		78	0.994	0.927	102.9	51.9	4.7	0.6	0.2	0.1
15	32.9	6.9	629	652		0.05		79	1.01	0.956	42.7	20.2	3	0.6	0.2	0.1
16	33.1	7.4				0.05		79	1.04	0.99	57.1	26.5	3.9	0.9	0.6	0.2
30	32.8	9.5	634	663		0.15		79	1.02	0.977	34.1	16.6	2.6	0.4	0.4	0.1
31	33.1	10.7				0		79	1.22	1.11	61	27.3	4.8	1	0.7	0.3
45	33.1	12.5	640	668		0		80	1.02	0.986	30.1	15	2.3	0.6	0.3	0.2
46	33.1	12.8				0		80	1.22	1.12	38.4	18.1	2.9	0.4	0.2	0
60	33.1	15.3	646	671		0.1		80	1.02	1	30.6	14.1	2.5	0.6	0.2	0.1
61	32.8	15.9				0		80	1.24	1.14	43.4	17.8	2.8	0.5	0.4	0.3
66	33.2	17.7	650	674		0		80	1.03	1.01	32.8	16.4	2.1	0.6	0.5	0.4
67	33.1	18.2						80	1.24	1.14	26.6	10.5	1.6	0.5	0.4	0.1

WD 43 - Test #6 - Jet A with Stadis 450 and FSII, 5-ppm DCI4A

			Conductivity		Aqua-glo	Gravimetric	IFT	Temp	Turbidity			Particle Counts				
Time	Flow rate, gpm	DP	Upstream	Downstream	ppm	mg/L	mN/m	F	25	90	4	6	14	21	25	30
Pre-conditioning																
0	3.2	0.5	584	301	1		36.15	78	0.547	0.805	21.9	6.1	0.1	0	0	0
5	3.1	0.5	589	301					0.548	0.807						
10	3.1	0.5	600	328					0.549	0.808						
15	3.1	0.5	603	357	1.5			82	0.549	0.808	137.1	30	0.7	0	0	0
100 ppm water challenge																
0	33	5.1	600	401	1.5			77	0.55	0.806	2.3	1.2	0	0	0	0
5	32.9	5.7	530	474	1.5			77	0.559	0.814	2	0.9	0.1	0.1	0.1	0
10	33.1	5.9	589	486	1.5			77	0.565	0.818	22.6	9	0.9	0.1	0.1	0
15	33	6						77	0.58	0.825						
20	32.9	6	597	543	2			77	0.592	0.831	23.4	10.9	1.3	0.1	0.1	0
25	33	6.1						77	0.597	0.833						
30	33	6.2	597	575	2			77	0.611	0.841	32.9	14.1	1.3	0.3	0.1	0.1
35	33	6.2						77	0.62	0.844						
40	33	6.3	603	592	2			77	0.629	0.847	34.9	14.4	1.6	0.5	0.3	0.1
45	32.9	6.3						77	0.638	0.853						
50	33	6.3	606	606	1.5			77	0.645	0.855	37.6	15.4	1.9	0.6	0.2	0.2
55	32.9	6.3						77	0.654	0.859						
60	32.9	6.3	608	617	2		42.17	77	0.66	0.862	44	18.5	1.9	0.5	0.4	0.1
0.5% water challenge																
0	33	6.2	613	625	2			77	0.668	0.867	18.5	8.4	1.1	0.2	0.1	0.1
5	33.1	6.8	605	630	2			77	0.672	0.872	374.4	153.7	9.6	2.6	1.6	0.5
10	33.1	6.9						77	0.686	0.88						
15	32.9	6.9	613	628	2			78	0.702	0.891	415.9	172.3	10.4	3.7	2.3	1
20	33.1	7.1						78	0.729	0.902						
30	32.9	7.1	609	639	2		42.17	78	0.756	0.915	469.4	192.6	13.8	4.6	2.3	1.1
3% water challenge																
0	33.1	6.5	619	622	2			77	0.806	0.943	76.8	35.9	2.4	0.7	0.5	0.2
2	33.1	7.7	618	644	2			78	0.895	0.946	1031.9	416.5	24.3	7.1	5.1	2.9
5	33.2	8.2	614	636	2			78	0.883	0.944	1170.9	474	21.1	6.6	3.3	1.9
10	33.1	8.2	618	636	2			78	0.881	0.951	1013.4	416.5	20.3	5.9	3.8	2.1
Solids																
0	33	6.6	613	638		0		77	0.945	0.994	64	33.9	3.6	0.5	0.4	0.4
15	33.1	7.2	615	657		0		77	0.977	1.01	33.4	14.4	1.6	0.4	0.2	0.2
16	33.2	7.4				0		77	0.994	1.02	40.4	18.4	2.8	0.7	0.4	0.1
30	33	15.2	612	664		0		78	1.04	1.09	355.1	32.5	2.1	0.2	0.2	0.1
31	32.9	17.5				0		78	1.09	1.19	553.9	45	2	0.6	0.4	0.2